Chapter 14
Spillways and Outlet Works

14-1. Function of Spillways and Outlet Works

Spillways and outlet works are necessary to provide capability to release an adequate rate of water from the reservoir to satisfy dam safety and water control regulation of the project. Sections 4-2 and 4-3 in EM 1110-2-3600 provide general descriptions of types and operation requirements for spillways and outlet works, respectively.

a. Spillway adequacy. While the outflow capability must be provided throughout the operational range of the reservoir, the focus of hydrologic studies is usually on the high flows and spillway adequacy. Dam failures have been caused by improperly designed spillways or by insufficient spillway capacity. Ample capacity is of great importance for earthfill and rockfill dams, which are likely to be destroyed if overtopped; whereas concrete dams may be able to withstand moderate overtopping.

b. Spillway classification. Spillways are ordinarily classified according to their most prominent feature, either as it pertains to their shape, location, or discharge channel. Spillways are often referred to as controlled or uncontrolled, depending on whether they are gated or ungated. EM 1110-2-1603 describes a variety of spillway types and provides hydraulic principles, design criteria, and results from laboratory and prototype tests.

c. Outlet works. Outlet works serve to regulate or release water impounded by a dam. It may release incoming flows at a reduced rate, as in the case of a detention dam; divert inflows into canals or pipelines, as in the case of a diversion dam; or release stored-water at such rates as may be dictated by downstream needs, evacuation considerations, or a combination of multiple-purpose requirements.

d. Outlet structure classification. Outlet structures can be classified according to their purpose, their physical and structural arrangement, or their hydraulic operation. EM 1110-2-1602 provides information on basic hydraulics, conduits for concrete dams, and conduits for earth dams with emphases on flood-control projects. Appendix IV of EM 1110-2-1602 provides an illustrative example of the computation of a discharge rating for outlet works.

e. Low level outlets. Low level outlets are provided to maintain downstream flows for all levels of the reservoir operational pool. The outlets may also serve to empty the reservoir to permit inspection, to make needed repairs, or to maintain the upstream face of the dam or other structures normally inundated.

f. Outlets as flood-control regulators. Outlet works may act as a flood-control regulator to release waters temporarily stored in flood control storage space or to evacuate storage in anticipation of flood inflows. In this case, the outflow capacity should be able to release channel capacity, or higher. The flood control storage must be evacuated as rapidly as safely possible, in order to maintain flood reduction capability.

14-2. Spillway Design Flood

a. Spillway design flood analyses. Spillway design flood (SDF) analyses are performed to evaluate the adequacy of an existing spillway or to size a spillway. For a major project, the conservative practice in the United States is to base the spillway design flood on the probable maximum precipitation (PMP). The PMP is based on the maximum conceivable combination of unfavorable meteorological events. While a frequency is not normally assigned. a committee of ASCE has suggested that the PMP is perhaps equivalent to a return period of 10,000 years.

b. Probable maximum flood. The PMF inflow hydrograph is developed by centering the PMP over the watershed to produce a maximum flood response. The unit hydrograph approach, described in Chapter 7 of this manual, is usually applied. Section 13-5 of EM 1110-2-1417 contains information on PMP determination and computation of the PMF.

c. Flood hydrographs. The inflow design flood hydrographs are usually for rainfall floods. Normally, such floods will have the highest peak flows but not always the largest volumes. When spillways of small capacities in relation to these inflow design flood peaks are considered, precautions must be taken to ensure that the spillway capacity will be sufficient to evacuate storage so that the dam will not be overtopped by a recurrent storm, and prevent the flood storage from being kept partially full by a prolonged runoff whose peak, although less than the inflow design flood, exceeds the spillway capacity. To meet these requirements, the minimum spillway capacity should be in accord with the following general criteria (Hoffman 1977):

(1) In the case of snow-fed perennial streams, the spillway capacity should never be less than the peak discharge of record that has resulted from snowmelt runoff.

(2) The spillway capacity should provide for the evacuation of sufficient surcharge storage space so that in routing a succeeding flood, the maximum water surface does not exceed that obtained by routing the inflow design flood. In general, the recurrent storm is assumed to begin 4 days after the time of peak outflow obtained in routing the inflow design flood.

(3) In regions having an annual rainfall of 40 in. or more, the time interval to the beginning of the recurrent storm in criterion (2) should be reduced to 2 days.

(4) In regions having an annual rainfall of 20 in. or less, the time interval to the beginning of the recurrent storm in criterion (2) may be increased to 7 days.

14-3. Area and Capacity of the Reservoir

a. Reservoir capacity and operations. Dam designs and reservoir operating criteria are related to the reservoir capacity and anticipated reservoir operations. The reservoir capacity and reservoir operations are used to properly size the spillway and outlet works. The reservoir capacity is a major factor in flood routings and may determine the size and crest elevation of the spillway. The reservoir operation and reservoir capacity allocations will determine the location and size of outlet works for the controlled release of water for downstream requirements and flood control.

b. Area-capacity tables. Reservoir area-capacity tables should be prepared before the final designs and specifications are completed. These area-capacity tables should be based on the best available topographic data and should be the final design for administrative purposes until superseded by a reservoir resurvey. To ensure uniform reporting of data for design and construction, standard designations of water surface elevations and reservoir capacity allocations should be used.

14-4. Routing the Spillway Design Flood

a. Discharge facilities. The facilities available for discharging inflow from the spillway design flood depend on the type and design of the dam and its proposed use. A single dam installation may have two or more of the following discharge facilities: uncontrolled overflow spillway, gated overflow spillway, regulating outlet, and power plant. With a reservoir full to the spillway crest at the beginning of the design flood, uncontrolled discharge will begin at once. Surcharge storage is created when the outflow capacity is less than the inflow and the excess water goes into storage, causing the pool level to rise above spillway crest. The peak outflow will occur at maximum pool elevation, which should always be less, to some degree, than the peak inflow.

b. Gated spillway. With a gated spillway, the normal operating level is usually near the top of the gates, although at times it may be drawn below this level by other outlets. A gated spillway's main purpose is to maximize available storage and head, while at the same time limiting backwater damages by providing a high initial discharge capacity. In routing the spillway design flood, an initial reservoir elevation at the normal full pool operating level is assumed. Operating rules for spillway gates must be based on careful study to avoid releasing discharges that would be greater than would occur under natural conditions before construction of the reservoir. By gate operation, releases can be reduced and additional water will be held in storage, which is called “induced-surcharge storage.” The release rates should be made in accordance with spillway gate regulation schedules developed for each gated reservoir. EM 1110-2-3600 Section 4-5 describes induced surcharge storage and the development and testing of the regulation schedules.

c. Surcharge storage. The important factor in the routing procedure is the evaluation of the effect of storage in the upper levels of the reservoir, surcharge storage, on the required outflow capacity. In computing the available storage, the water surface is generally considered to be level. There will be a sloping water surface at the head of the reservoir due to backwater effect, and this condition will create an additional “wedge storage.” However, in most large and deep reservoirs this incremental storage can be neglected.

d. Drawdown. If a reservoir is drawn down at the time of occurrence of the spillway design flood, the initial increments of inflow will be stored with the corresponding reduction in ultimate peak outflow. Therefore, for maximum safety in design it is generally assumed that a reservoir will be full to the top of flood-control pool at the beginning of the spillway design flood.

e. Large flood-control storage reservations. There may be exceptions to the above criteria in the case of reservoirs with large reservations for flood-control storage. However, even in such cases, a substantial part (> 50 percent) of the flood-control storage should be considered as filled by runoff from antecedent floods. The effect on the economics and safety of the project should be analyzed before adopting such assumptions. ER 1110-8-2(FR) contains guidance on inflow design flood development and application.

f. Release rates. Assuming a reservoir can be significantly drawn down in advance of the spillway design flood by using a short-term flood warning system is generally not acceptable for several reasons. The volume that can be released is the product of the total rate of discharge at the dam times the warning time. Because the warning time is usually short, except on large rivers, the release rate must be the greatest possible without flood damage downstream. Even under the most favorable conditions, it is unlikely that the released volume will be significant, relative to the volume of the spillway design flood.

14-5. Sizing the Spillway

a. Storage and spillway capacity. In determining the best combination of storage and spillway capacity to accommodate the selected inflow design flood, all pertinent factors of hydrology, hydraulics, design, cost, and damage should be considered. In this connection and when applicable, consideration should be given to the following factors:

(1) The characteristics of the flood hydrograph.

(2) The damage which would result if such a flood occurred without the dam.

(3) The damage which would result if such a flood occurred with the dam in-place.

(4) The damage which would occur if the dam or spillway were breached.

(5) Effects of various dam and spillway combinations on the probable increase or decrease of damages above or below the dam.

(6) Relative costs of increasing the capacity of the spillways.

(7) The use of combined outlet facilities to serve more than one function.

b. Outflow characteristics. The outflow characteristics of a spillway depend on the particular device selected to control the discharge. These control facilities may take the form of an overflow weir, an orifice, a tube, or a pipe. Such devices can be unregulated, or they can be equipped with gates or valves to regulate the outflow.

c. Flood routing. After a spillway control of certain dimensions has been selected, the maximum spillway discharge and the maximum reservoir water level can be determined by flood routing. Other components of the spillway can then be proportioned to conform to the required capacity and the specific site conditions, and a complete layout of the spillway can be established. Cost estimates of the spillway and dam can then be made. Estimates of various combinations of spillway capacity and dam height for an assumed spillway type, and of alternative types of spillways, will provide a basis for the selection of the most economical spillway type and the optimum relation of spillway capacity to the height of the dam.

d. Maximum reservoir level. The maximum reservoir level can be determined by routing the spillway design flood hydrograph using sequential routing procedures and the proposed operation procedures. This is a basic step in the selection of the elevation of the crest of the dam, the size of the spillway, or both.

e. Peak rate of inflow. Where no flood storage is provided, the spillway must be sufficiently large to pass the peak of the flood. The peak rate of inflow is then of primary interest, and the total volume in the flood becomes less important. However, where a relatively large storage capacity above normal reservoir level can be made economically available by a higher dam, a portion of the flood volume can be retained temporarily in reservoir surcharge space, and the spillway capacity can be reduced considerably. If a dam could be made sufficiently high to provide storage space to impound the entire volume of the flood above normal storage level, theoretically, no spillway other than an emergency type would be required, provided the outlet capacity could evacuate the surcharge storage in a reasonable period of time in anticipation of a recurring flood. The maximum reservoir level would then depend entirely on the volume of the flood, and the rate of inflow would be of no concern. From a practical standpoint, however, relatively few sites will permit complete storage of the inflow design flood by surcharge storage.

f. Overall cost. The spillway length and corresponding capacity may have an important effect on the overall cost of a project because the selection of the spillway characteristics is based on an economic analysis. In many reservoir projects, economic considerations will necessitate a design utilizing surcharge. The most economical combination of surcharge storage and spillway capacity requires flood routing studies and economic studies of the costs of spillway-dam combinations. Among the many economic factors that may be considered are damage due to backwater in the reservoir, cost-height relations for gates, and utilization in the dam of material excavated from the spillway channel. However, consideration must still be given to the minimum size spillway which must be provided for safety.

g. Comprehensive study. The study may require many flood routings, spillway layouts, and spillway and dam estimates. Even then, the study is not necessarily complete because many other spillway arrangements could be considered. A comprehensive study to determine alternative optimum combinations and minimum costs may not be warranted for the design of some dams. Judgment on the part of the designer would be required to select for study only those combinations which show definite advantages, either in cost or adaptability. For example, although a gated spillway might be slightly cheaper than an ungated spillway, it may be desirable to adopt the latter because of its less complicated construction, its automatic and trouble-free operation, its ability to function without an attendant, and its less costly maintenance.

14-6. Outlet Works

a. Definition. An outlet works consists of the equipment and structures which together release the required water for a given purpose or combination of purposes. Flows through river outlets and canal or pipeline outlets change throughout the year and may involve a wide range of discharges under varying heads. The accuracy and ease of control are major considerations and a great amount of planning may be justified in determining the type of control devices that can be best utilized.

b. Description. Usually, the outlet works consist of an intake structure, a conduit or series of conduits through the dam, discharge flow control devices, and an energy dissipating device where required downstream of the dam. The intake structure includes a trash-rack, an entrance transition, and stop-logs or an emergency gate. The control device can be placed at the intake on the upstream face, at some point along the conduit and be regulated from galleries inside the dam, or at the downstream end of the conduit with the operating controls placed in a gate-house on the downstream face of the dam. When there is a power plant or other structure near the face of the dam, the outlet conduits can be extended farther downstream to discharge into the river channel beyond these features. In this case, a control valve may be placed in a gate structure at the end of the conduit.

c. Discharge. Discharges from a reservoir outlet works fluctuate throughout the year depending upon downstream water needs and reservoir flood control requirements. Therefore, impounded water must be released at specific regulated rates. Operating gates and regulating valves are used to control and regulate the outlet works flow and are designed to operate in any position from closed to fully open. Guard or emergency gates are designed to close if the operating gates fail, or where dewatering is desired to inspect or repair the operating gates.

d. Continuous low-flow releases. Continuous low-flow releases are usually required to satisfy the needs of fish, wildlife and existing water rights downstream from the dam. When the low-flow release is small, one or two separate small bypass pipes, with high-pressure regulating valves, are provided to facilitate operations. Flood-regulating gates may be used for making low-flow releases when those low-flow releases require substantial gate openings (EM 1110-2-1602).

e. Uses of an outlet works. An outlet works may be used for diverting the river flow or portion thereof during a phase of the construction period, thus avoiding the necessity for supplementary installations for that purpose. The outlet structure size dictated by this use rather than the size indicated for ordinary outlet requirements may determine the final outlet works capacity.

f. Intake level. The establishment of the intake level is influenced by several considerations such as maintaining the required discharge at the minimum reservoir operating elevation, establishing a silt retention space, and allowing selective withdrawal to achieve suitable water temperature and/or quality. Dams which will impound waters for irrigation, domestic use, or other conservation purposes must have the outlet works intake low enough to be able to draw the water down to the bottom of the allocated storage space. Further, if the outlets are to be used to evacuate the reservoir for inspection or repair of the dam, they should be placed as low as practicable. However, it is usual practice to make an allowance in a reservoir for inactive storage for silt deposition, fish and wildlife conservation, and recreation.

g. Elevation of outlet intake. Reservoirs become thermally stratified, and taste and odor vary between elevations. Therefore, the outlet intake should be established at the best elevation to achieve satisfactory water quality for the purpose intended. Downstream fish and wildlife requirements may determine the temperature at which the outlet releases should be made. Municipal and industrial water use increases the emphasis on water quality and requires the water to be drawn from the reservoir at the elevation which produces the most satisfactory combination of odor, taste, and temperature. Water supply releases can be made through separate outlet works at different elevations if requirements for the individual water uses are not the same and the reservoir is stratified.

h. Energy-dissipating devices. The two types of energy dissipating devices most commonly used in conjunction with outlet works on concrete dams are hydraulic jump stilling basins and plunge pools. On some dams, it is possible to arrange the outlet works in conjunction with the spillway to utilize the spillway-stilling device for dissipating the energy of the water discharging from the river outlets. Energy-dissipating devices for free-flow conduit outlet works are essentially the same as those for spillways.